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(71) Applicant (*for all designated States except US*): ABB FLÄKT AKTIEBOLAG [SE/SE]; Sickla Allé 13, Nacka, S-120 86 Stockholm (SE).

(72) Inventor; and
(75) Inventor/Applicant (*for US only*): PERSSON, Torsten [SE/SE]; Trädgårdsgatan 11, S-340 36 Moheda (SE).

(74) Agents: JENKLER, Malte et al.; Asea Brown Boveri AB, Patent, Stockholm Office, S-120 86 Stockholm (SE).

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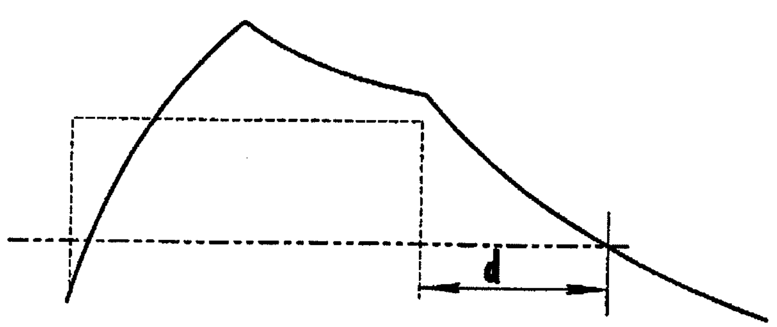

(57) Abstract

In a method for use in an electrostatic precipitator unit, comprising discharge electrodes and collecting electrodes between which a varying high voltage is maintained, to control a pulsating direct current supplied to the electrodes, the frequency, pulse height and/or pulse length of the pulsating direct current are varied, so as to obtain a plurality of frequency-height-length combinations. A first point of time for the end of the supplied current pulse, and a second point of time when the voltage between discharge electrodes and collecting electrodes has fallen to a predetermined level U_{ref}, are determined. The length of a time interval between the first point of time and the second point of time is determined, and the length of the time interval is used to select the frequency-height-length combination of the pulsating direct current.

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METHOD TO CONTROL CURRENT SUPPLY TO AN ELECTROSTATIC PRECIPITATOR

FIELD OF THE INVENTION

The present invention relates to a method for use in an electrostatic precipitator unit, comprising discharge electrodes and collecting electrodes between which a varying high voltage is maintained, to control a pulsating direct current supplied thereto.

The method is especially well suited when the pulsating direct current is generated by a pulse means, such that the length, height and frequency of the pulses can be varied independently of each other.

The method can also be used when the pulsating current has the form of a pulse train which is synchronised with the frequency of the mains voltage and in which the pulses are generated by supplying a part of a half-wave of the mains voltage by means of a phase-angle-controlled rectifier (thyristor), after step-up transformation to the electrodes of the precipitator, whereupon a plurality of periods of the mains voltage are allowed to pass without any current being supplied to the electrodes.

BACKGROUND OF THE INVENTION

Electrostatic precipitators are often the most preferred dust separator option, especially for flue gas cleaning. They have a robust design and are highly reliable in operation. Moreover, they are very efficient, degrees of separation above 99.9% are not unusual. Since, when compared with textile barrier filters, their operating costs are low and the risk of breakdown and stoppage owing to malfunction is considerably smaller, they are a natural choice in many contexts.

A problem that is often difficult to master appears when dust with high resistivity is to be separated. In such operating cases one is often forced to operate with extremely unfavourable operating parameters due to the risk for partial discharges in the gradually growing dust layer on the collecting electrodes. When partial discharges occur in the dust layer the effect will i.a. be emission of charges and dust from the collecting electrodes, so-called back corona.

In order to optimise the operation and reduce the energy consumption at the same time as the separation is improved, several methods for pulse feeding of the current to the filter have been suggested. Examples are found in US-4,052,177 and US-4,410,849. The former publication suggests feeding of pulses in the order of microseconds, which means that the rectifiers become very expensive. The latter publication suggests pulses in the order of milliseconds, which may rather simply be achieved by selectively controlling quite common thyristor rectifiers, to which mains frequency alternating current are supplied.

By pulse-width modulation of an intermediate frequency of 10 to 50 kHz, pulse lengths down to 0.02-0.10 ms and a quick adjustment with reliable control of the current supply to the electrostatic precipitator are obtained by relatively simple means. Such methods are described in i.a. DE 35 22 568 and WO 88/07413.

With the new techniques, the number of control parameters have increased and, hence, the complexity of the control systems. Unfortunately, this also means that the adjustment itself increases the disturbance in the function of the separator. In the same way as the emissions increase when the filter is being rapped, the emissions will increase during the time the adjustment proceeds or set control parameters are being checked.

Therefore, it is highly desirable to provide a method for quick and reliable adjustment of the current supply to the electrostatic precipitator based only on electrical

measurements in the precipitator involved or associated rectifier. It has been shown that even if the rapping very strongly influences the dust concentration of the outgoing gas from the precipitator, the current-to-voltage ratio in a precipitator is only marginally changed thereby.

Some tests with optimisation based only on measurement of electrical quantities have been performed, and as examples thereof reference is made to US-4,311,491, EP-465 547 and EP-184 922. These examples have, however, remaining shortcomings when it comes to adaptability to process changes, and reliability when it comes to finding the setting, which gives minimum energy consumption during varying conditions when separating highly resistive dust.

The older technique known to us as the closest prior art to the present invention is disclosed in US-4,690,694 (DE 35 26 009). In this publication an evaluation of the rate of the voltage drop from the peak value during a current pulse to the level for corona on-set is suggested. However, this suggestion has been shown to result in totally wrong conclusions and often it does not give any information on optimal current supply.

THE OBJECT OF THE INVENTION

The methods hitherto tested, when separating highly resistive dust, have been found not always to yield the optimum parameter combination. This is the fact particularly for the methods based on measurement of the dust concentration, but it also applies to hitherto proposed methods that are based on measurement of electrical quantities.

It is a main object of the present invention to provide an improved method for selection of operating parameters for electrostatic precipitators when separating "difficult" dust, for instance dust having high resistivity.

Another object of the present invention is to provide a method, based on measurement of electrical quantities only in a certain electrostatic unit, which quite general gives a quicker and safer adjustment of the electrostatic precipitator unit.

It is especially an object of the present invention to provide a method, which can be used for every pulse feeding all the way down to pulse lengths of the order of 1 microsecond and therebelow, and which without complicated calculation programs with great safety gives information on the best operating point for the electrostatic precipitator.

SUMMARY OF THE INVENTION

The present invention relates to a method for use in an electrostatic precipitator unit, comprising discharge electrodes and collecting electrodes between which a varying high voltage is maintained, to control a pulsating direct current supplied thereto. The frequency, pulse height and/or pulse length of the pulsating direct current are varied, so as to obtain a plurality of frequency-height-length combinations.

In the method according to the invention, a first point of time for the end of the supplied current pulse, and a second point of time, when the voltage between the discharge electrodes and collecting electrodes has fallen to a predetermined level U_{ref}, is determined. The length of a time interval between the first point of time and the second point of time is determined, and the length of the time interval is used to select the frequency-height-length combination of the pulsating direct current.

GENERAL DESCRIPTION OF THE INVENTION

One of the fundamental observations in the operation of electrostatic precipitators is that the separation becomes more efficient when the voltage between discharge electrodes and collecting electrodes is increased. It is essentially found that the physical migration velocity of the particles depends on the square of the electric field strength and, thus, also on the square of the voltage.

Efficient separation therefore requires a high voltage, the higher the better. The usable voltage interval is limited upwards by the fact that flashover occurs between the electrodes. In problem-free operation, one therefore tries to operate as close to the flashover limit as possible.

High voltage essentially also means that the current density becomes high. If the dust that is separated conducts current well, this involves no problem, but if the dust has high resistivity and the current density in the gas is high, the separated dust layer on the collecting electrodes will be charged such that the electric field strength in the layer will be sufficient to conduct the same high current density through the dust layer. This often results in electric breakdown of the dust layer, so-called back corona, if the current density is not limited.

It has been known for over 50 years that pulse feeding of current to electrostatic precipitators improves the performance of the precipitator when the dust is difficult to separate, i.e. is highly resistive. This is considered to depend on the fact that the average value of the current can be kept down, without considerably deteriorating the distribution of the current at the collecting electrodes. As mentioned above, this has resulted in attempts, sometimes with highly complex equipment, to supply the necessary energy to the precipitator by also using very short pulses.

Gradually, it was found that excellent results were obtained also with pulses of the same order as the half-

waves of the regular alternating voltage used in the distribution networks. This was explained by the fact that charge variations in the dust layer, which in charge growth cause the so-called back corona, have a time constant of about 1 second. This should, however, not be interpreted to mean that it takes 1 second to charge the layer, although this mistake is frequently made, but that it takes about one second for the layer to be discharged when the charging has ceased. The charging is controlled merely by the supplied charge, i.e. the size of the current. Thus, the charging can be effected in less than one millisecond if the current intensity is sufficient.

An electrostatic precipitator unit can be regarded as a capacitor with a relatively high leakage current. The higher the voltage is above the ignition voltage of the corona discharge, the greater the leakage current. This also results in that the voltage then is falling relatively quickly if no new charge is supplied.

If the collecting electrodes are clean or coated with a layer of dust, the resistivity of which is low, the corona discharge expires approximately at the ignition voltage and, thus, the voltage drop ceases. However, this does not apply in general. When the layer of dust has sufficiently high resistivity, the level is controlled by the current density, discharges also take place in the layer of dust. This leads to generation of charges of the opposite polarity and reduces the extinction voltage of the corona, such that the precipitator unit can discharge to a considerably lower level. The discharge also proceeds more rapidly, the leakage current at a given voltage is greater.

The supply of current in the form of pulses to a precipitator unit usually results in an increasing voltage during the pulse and a decreasing voltage between the pulses, see Figs 1 and 2. As mentioned above, the rate of increase during the pulse depends on the size of the current, and the rate of discharge depends on the voltage

level at issue and whether ionisation also takes place at the dust layer, so-called back corona.

The consequences of back corona, however, will be noticed even during the pulse. When one has supplied to the dust layer the charge that is necessary for the field strength in the dust layer to result in partial discharges in the layer, the current increases sharply at a constant voltage. As a rule, there are other limitations, which imply that in spite of a continued supply of charge there will be a falling voltage. The time dependency of the voltage will fundamentally be the one shown in Fig. 3. An actually recorded curve is shown in Fig. 4.

In the above-mentioned US 4,690,694 this fact is unknown. This publication suggests that one should strive to make the time between the peak of the voltage and the extinction of the corona as long as possible. When studying Fig. 4, it will be appreciated that this time can be made to be of any length while the corona proceeds with extremely poor conditions prevailing in the precipitator unit.

Since this results in the fact that at the end of the pulse there will be a comparatively low voltage and a comparatively high current, the voltage after the pulse, however, will decrease drastically. This knowledge leads to the present invention which suggests that use be made of the actually discharging part of the voltage curve as a criterion for controlling the current supply to the precipitator unit. This is carried out by determining the length of a time interval which begins when the current pulse ends and ends when the voltage between discharge electrodes and collecting electrodes has fallen to a predetermined level. This level should be at or above the ignition voltage of the corona, suitably not more than 25% above the same. The length of the interval is used as a control parameter, in the first place such that one tries to operate close to the conditions that result in a maximum length of the interval.

According to the present invention, it is therefore suggested that the length, height and frequency of the pulses be varied, such that, for instance, for each frequency the maximum possible length of the interval is established and then this procedure is repeated for other frequencies and these interval lengths are used to select parameters for the continued operation. Suitably, an investigation is made of a sufficiently great frequency range such that a certain frequency is found, which gives the absolutely longest interval, above which frequency a shorter interval is again obtained, and the operation is continued at a frequency close or equal to this value. As the gas to be cleaned changes, the size of the pulse is then varied at this frequency, thereby being close to the flashover limit. Preferably, precisely the frequency is chosen that gives a maximum for the length of the interval.

In a suitable embodiment, use is made of a special pulse means for supplying the current to the electrostatic precipitator unit. When using special pulse means, such as high-frequency converters, the pulse frequency can be varied, for instance, between 1 Hz and 10 kHz, preferably between 1 Hz and 1 kHz.

When using mains frequency and thyristors which, via a transformer, transmit a part of a half-wave from an essentially sinusoidal voltage to the electrostatic precipitator unit, it is necessary to accept that pulse length and pulse height vary together in a fashion that is determined by the mains voltage and that the pulse frequency can only be varied as submultiples of the mains frequency.

The preferred variation of the shape of the pulses is such that the maximum height of the pulse is chosen which is available with the existing equipment, and to obtain a varying charge, the pulse length is varied. One suitably begins with a relatively low frequency and determines at this frequency the pulse shape that gives a maximum interval length and then repeats this procedure at successively higher frequencies. When a further frequency increase

results in a reduced maximum length, the adjustment is interrupted.

An alternative procedure implies that during the adjustment, one keeps the frequency constant and begins with a short pulse the length and/or charge of which is/are successively increased as long as this results in an increased length of interval. For instance, it is also possible to keep the charge of the pulses constant and vary the frequency, beginning at a low value.

The choice of the control algorithm depends to a high degree on the design of the pulse means.

The advantages of the invention are most significant when the current pulses have a short decay time, or at least finally decrease at a high rate.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will now be described in more detail with reference to the accompanying drawings, in which

Fig. 1 shows the fundamental time dependency of the voltage between the electrodes for an electrostatic precipitator unit to which a relatively short current pulse is supplied;

Fig. 2 shows the same for a somewhat longer current pulse which, however, does not result in back corona from the dust layer;

Fig. 3 shows the fundamental time dependency of the voltage between the electrodes for an electrostatic precipitator unit to which such a great current pulse is supplied that back corona from the dust layer limits the voltage increase;

Fig. 4 shows the time dependency of the voltage, corresponding to Fig. 3, measured on an electrostatic precipitator unit in operation;

Fig. 5 shows a simplified wiring diagram for a device, which is suitable for carrying out the suggested method.

DESCRIPTION OF A PREFERRED EMBODIMENT

Fig. 1 shows the time dependency of the voltage as a full line when an electrostatic precipitator unit is supplied with a current pulse, with a constant amplitude, indicated by a dashed line. The current pulse contains a relatively small amount of charge. The voltage increases during the entire current pulse and then again decreases down to the corona ignition voltage. A double arrow "d" indicates the length of an interval between the end of the current pulse and the point of time when the voltage has fallen to a selected voltage level, U_{ref}, which in this case is the ignition voltage of the corona. The dash-dot line indicates this voltage level U_{ref}. The determination of the ignition voltage of the corona can be made, for instance, by a method as described in US 5,477,464.

Fig. 2 shows in the same way the time dependency of the voltage when the current pulse has been somewhat extended with its amplitude maintained. The pulse charge, however, is not so great that back corona starts. The interval "d" is here considerably longer.

Fig. 3 shows the time dependency of the voltage when the current pulse has been extended such that the charge is sufficient for the back corona to start during the pulse. This leads to a deformation by the voltage increase being interrupted and the voltage beginning to decrease despite a continued supply of charge. The voltage between the electrodes at the end of the current pulse is in this case considerably lower than in Fig. 2. The voltage drops between the pulses considerably below the predetermined level U_{ref}.

The interval "d" obtained in Fig. 3 is considerably shorter than the one in Fig. 2. This corresponds in a correct fashion to the considerably impaired function of the

electrostatic precipitator unit in operation according to Fig. 3. If the method as suggested in said US 4,690,694 is used, no information on this difference will be obtained. The time interval from voltage maximum to corona starting voltage is approximately the same in both Figures. As a result, the method according to US 4,690,694 has so pronounced drawbacks as to make it inappropriate.

Figs 1-3 illustrate for the sake of clarity simplified relations. Fig. 4 shows a curve recorded by means of an oscillograph and displaying the voltage in normal operation with an electrostatic precipitator. The current pulse is considerably longer than the optimal one that would be obtained with the method here suggested. The current average at issue is more than three times as great as the one in optimal operation.

Fig. 5 is a fundamental wiring diagram of a voltage-converting device which supplies high-voltage direct current to a precipitator unit 1. The device comprises a three-phase rectifier bridge 2, a pulse generator 3, a transformer 4, a one-phase full-wave rectifier bridge 5, a choke 6, and control equipment 7 with precision resistors 8, 9 and 10.

The three-phase rectifier bridge 2 comprises six diodes 21-26 and is, via three conductors 27, 28, 29 connected to ordinary three-phase AC mains.

The pulse generator 3 comprises four transistors 31-34 and four diodes 35-38. The transistors are controlled by their bases being connected to the control equipment 7.

The full-wave rectifier bridge 5 consists of four diodes 51-54.

The control equipment 7 is connected not only to the transistors 31-34, but also to a precision resistor 8 in series with the precipitator unit 1, for measuring the current to the electrodes of the precipitator, and to a voltage divider comprising two resistors 9 and 10 connected between the electrodes of the precipitator unit for measuring the voltage between them.

The device functions as follows. Via the conductors 27-29, the rectifier bridge 2 is supplied with three-phase alternating current. This is rectified and is transferred, via conductors 11 and 12, as a direct current to the pulse generator 3. The control equipment 7 controls the conducting periods of the transistors 31-34 such that a pulse-width-modulated voltage, essentially formed as a square wave, is supplied, via conductors 13 and 14, to the primary side of the transformer 4.

The voltage induced in the secondary winding of the transformer 4 is rectified by the rectifier bridge 5 and, via the smoothing choke 6, the obtained direct current is supplied to the electrodes of the precipitator unit 1.

As mentioned above, the control equipment 7 controls the transistors 31-34 and moreover monitors the current and voltage of the precipitator via the resistors 8 and 10. Since the conducting periods of the transistors are controlled, the pulse width of the generated, essentially square-wave-formed current pulse can be varied and, consequently, both current and voltage in the precipitator are controlled.

In an exemplifying application of the invention, the above described device is thought to operate with an intermediate frequency of 50 kHz and a pulse frequency of 10 Hz. The pulse height is the maximum one for the means and the current is controlled so that the flashover limit is continuously sensed by varying the pulse length somewhat around an average value of about 1 ms.

At the adjustment the pulse frequency is decreased to 5 Hz and the pulse length is increased step-by-step during registration of the length of the time interval between the end of the current pulse and the point of time when the voltage has fallen to a determined level just above the ignition voltage of the corona. When increased pulse length gives a shorter interval the increase is interrupted. The maximum interval length is registered. At successively

increased pulse frequency, up to values above 10 Hz, the procedure is repeated so that for each frequency the maximum interval length is determined. The frequency for which the maximum interval length during the adjustment is registered, is used in the continued operation. At this frequency the pulse length is then varied in a usual manner so that essentially maximum current can be supplied. The interval between the adjustments is to be determined based on experience, but as the adjustment does not mean a total stoppage or a crucial disturbance it can without inconvenience be performed with short intervals if the operating parameters are varied.

ALTERNATIVE EMBODIMENTS

It goes without saying that the method according to the invention is not limited to the embodiment described above but can be varied in a number of ways within the scope of the appended claims.

For instance, the current pulse can be generated by phase-angle-controlled rectifiers transmitting at least part of a half-wave from an essentially sinusoidal mains voltage which after step-up transformation and rectification is supplied to the electrostatic precipitator unit. Moreover, any form of pulse means can be used in which the entire voltage decay or at least a great part thereof depends on the internal current between the electrodes of the precipitator unit. Particular caution, however, must be exercised if forced discharge, externally controlled, of the precipitator takes place. It is a condition of the invention that the registered magnitude depends on internal processes.

CLAIMS

1. A method in an electrostatic precipitator unit, comprising discharge electrodes and collecting electrodes, between which a varying high voltage is maintained, of controlling a pulsating direct current supplied to said electrodes, the frequency, pulse height and/or pulse length of the pulsating direct current being varied in an adjustment procedure such that a plurality of frequency-height-length combinations are obtained,

characterised in

that a first point of time for the end of the supplied current pulse is determined,

that a second point of time when the voltage between discharge electrodes and collecting electrodes has fallen to a predetermined level U_{ref}, is determined,

that the length of a time interval between the first point of time and the second point of time is determined, and

that the length of the time interval is used to select the frequency-height-length combination of the pulsating direct current for the continued operation.

2. A method as claimed in claim 1, characterised in that U_{ref} is selected above or equal to the ignition voltage of the corona discharge at the discharge electrodes, preferably not more than 25% above the ignition voltage.

3. A method as claimed in claim 1 or 2, characterised in

that the frequency-height-length combination for which the time interval is the longest is determined, and

that a pulse frequency close or equal to the one obtained at said frequency-height-length combination is selected for the continued operation.

4. A method as claimed in any one of the claims 1 to 3, whereby the pulses are generated by a pulse means, c h a r a c t e r i s e d in that the pulse frequency is varied between 1 Hz and 10 kHz, preferably between 1 Hz and 1 kHz.

5. A method as claimed in any one of the claims 1 to 3, whereby the pulses are generated by that phase-angle-controlled rectifiers transmit at least a part of a half-wave from an essentially sinusoidal mains voltage, which after step-up transformation and rectification is supplied to the electrostatic precipitator unit, c h a r a c t e r i s e d in

that the frequency is varied by that the phase-angle-controlled rectifiers are kept conducting during a part of a half-wave or a full half-wave and thereafter is kept essentially non-conducting during one or more half-waves.

6. A method as claimed in any one of the claims 1 to 4, whereby the pulses are generated by a pulse means in the form of a high-frequency converter, by pulse-width modulation of an intermediate frequency, and the intermediate frequency of the pulse means is between 1 kHz and 100 kHz, preferably between 10 kHz and 50 kHz,

c h a r a c t e r i s e d in that the pulse frequency is varied between 1 Hz and 10 kHz, preferably between 1 Hz and 1 kHz.

7. A method as claimed in any one of the claims 1 to 6, c h a r a c t e r i s e d in

that at the adjustment one begins with a frequency which is lower than the one involved for the operation precisely before the adjustment, and

that at successively increasing frequency one determines, for the frequency involved, the lowest time interval until one has passed a minimum, and thereafter selects pulse parameters close to those which gave maximum for the continued operation.

8. A method as claimed in any one of the claims 1 to 6, c h a r a c t e r i s e d in

that at the adjustment one keeps the frequency constant,

that one begins with a pulse length which is shorter than the one involved for the operation precisely before the adjustment, and

that at successively increasing pulse length one determines the length of the time interval until one has passed a maximum, and thereafter selects pulse parameters close to those which gave the maximum for the continued operation.

9. Method as claimed in any one of claims 1 to 6, c h a r a c t e r i s e d i n

that at the adjustment one keeps the charge of the pulse constant,

that at the adjustment one begins with a frequency which is lower than the one involved for the operation precisely before the adjustment, and that at successively increasing frequency one determines the length of the time interval until one has passed a maximum, and thereafter selects pulse parameters close to those which gave the maximum for the continued operation.

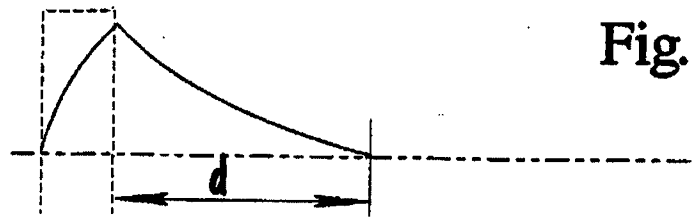

Fig. 1

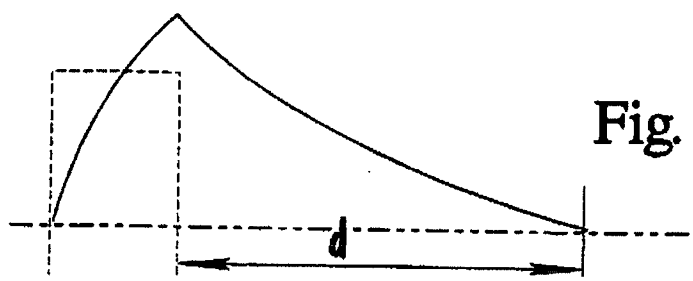

Fig. 2

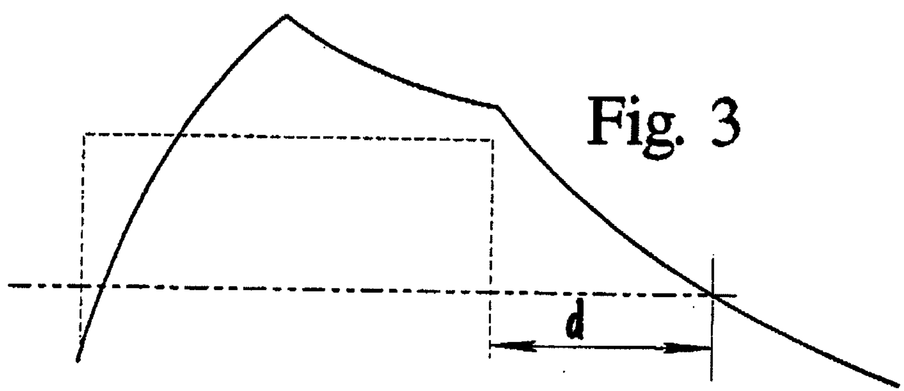

Fig. 3

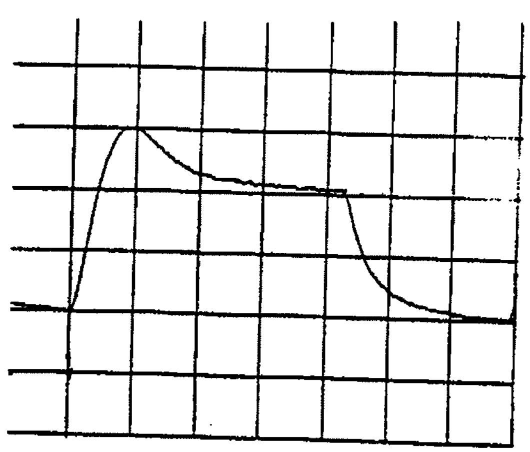

Fig. 4

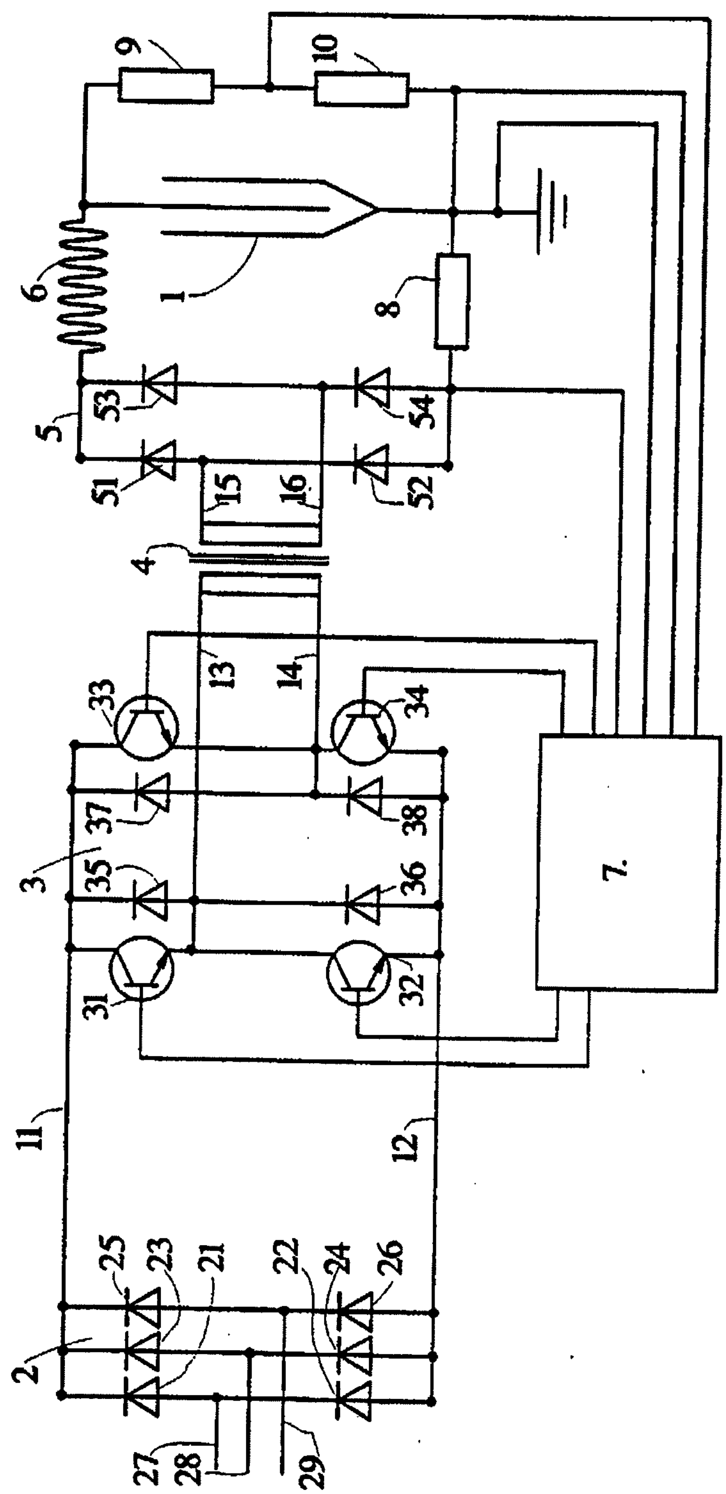
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Fig. 5

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/01575

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: B03C 3/68

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: B03C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4690694 A (F. ALIG ET AL), 1 Sept 1987 (01.09.87), column 2, line 39 - column 3, line 45 --	1-9
A	WO 9310902 A1 (ABB FLÄKT AB), 10 June 1993 (10.06.93), abstract --	1-9
A	WO 9011132 A1 (FLÄKT AB),. 4 October 1990 (04.10.90), abstract -- --------	1-9

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Date of the actual completion of the international search	Date of mailing of the international search report
22 December 1998	30 -12- 1998
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INTERNATIONAL SEARCH REPORT

Information on patent family members

01/12/98

International application No.

PCT/SE 98/01575

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